
CONTROL TECHNIQUES

18 Leak testing

Fig. 18.1 (previous page): First industrial leak tester for rims (2005).

18.1 Summary

Leak testing is the testing if gases escape from sealed components or systems. The Microflown sensor shows to be a competitive system for the leak testing industry.

The sensitivity (the lowest leak rate that can be measured) is of the same order of Helium systems ($3\cdot10^{-4}$ mbar l/s).

Advantage of this system is that the location of the leak can be found.

In this chapter several leak testing methods are explained and compared with the Microflown method.

18.2 Introduction

Although this application makes use of particle velocity measurements it is not an acoustic application in the sense that it solves an acoustic problem. Leak testing is the branch of nondestructive testing that is concerned with the escape of liquids, vacuum or gases from sealed components or systems.

Like other forms of nondestructive testing, leak testing has a great impact on the safety or performance of a product. Reliable leak testing saves costs by reducing the number of reworked products, warranty repairs and liability claims. The time and money invested in leak testing often produces immediate profit.

The three most common reasons for performing a leak test are:

Material loss- With the high cost of energy, material loss is increasingly important. By leak testing, energy is saved not only directly, through the conservation of fuels such as gasoline and LNG but also indirectly, through the saving of expensive chemicals and even compressed air.

Contamination - With stricter environmental regulations, this reason for testing is growing rapidly. Leakage of dangerous gases or liquids pollutes and creates serious personnel hazards.

Reliability- Component reliability has long been a major reason for leakage testing. Leak tests operate directly to assure serviceability of critical parts from pacemakers, rims, filters to refrigeration units.

The flow characteristics of a leak are often referred to as the conductance of the leak. Because the hole cannot usually be seen or measured, the quantity used to describe the leak is the conductance or leakage rate of a given fluid through the leak under given conditions. The leakage rate used as a measure of leak size must have dimensions equivalent to pressure, temperature, time and volume.

Leakage tightness is a relative term. Nothing made by man can ever be completely free of leakage and, in most cases, it is uneconomic to even try. A balance must be struck between the increasing cost of finding smaller leaks and their importance to the functioning of the unit over its useful life. Leakage tight therefore has no meaning except in relation to the substance which is to be contained, its normal operating conditions, and the objectives with respect to safety, contamination, and reliability. For example, most refrigeration systems will continue to operate efficiently with 10% less refrigerant than originally charged. Studies indicate the useful life of these units to be about 10 years. Thus, on a refrigeration system containing a normal Freon charge of 20 lbs., one might find leakage smaller than 3 ounces uneconomical to repair.

Fig. 18.2: First prototype of the leak detection probe.

18.3 Leak detection methods

Whether a component or a system is leak-tight depends on the application. Absolutely leak tight components and systems do not exist. A component is considered technically leak tight if its leak rate remains below a value defined for this particular component.

The symbol for the volume leak rate is *Q* in [Pa*m^3/s] or [mbar*l/s]

Leak rate norms for rims

The norm dictates a rim should be rejected when the pressure drops more than 0,2 bar in 25 weeks at an initial overpressure of 2 bar (according to E.T.R.T.O. standards). The leak rate can be calculated by [2]:

$$Q = \frac{(P_1 - P_2) * V}{\Delta t}, \left[\frac{mbar * l}{s}\right] \tag{1}$$

P1 and ***P2*** are pressure readings as a certain small time interval, ***Δt***, ***V*** is the volume and P_{atm} is the atmospheric pressure

$$Q = \frac{(3bar - 2.8bar) * 25l}{25weeks} = 0.33*10^{-3}\left[\frac{mbar * l}{s}\right] \text{@ 2bar overpressure} \tag{2}$$

Available leak testing methods

Acoustic

Acoustic leak detection uses sonic or ultrasonic energy that is generated by a gas as it expands through an orifice. The sonic energy can easily detected by conventional microphones. This method is fairly simple and fast but is not very sensitive and reliable (the method was tested at Microflown Technologies).

Laser

This method uses a laser beam in order to detect a leakage. A test object is filled with a tracer gas to a certain overpressure. The outside of the test object is scanned with a CO_2 Laser beam. If the laser beam meets this gas escaping through a leakage, then the electrons of this gas are activated to a higher energy level by the laser beam, i.e. one or more electrons of the gas molecules are transported on a higher trajectory, when falling back on the original trajectory this energy is released again. This takes place by emission of photons (a light lightning with a certain frequency [colour]).

Hydrogen

In the past, leak detection with the search gas hydrogen was of little significance, because of the dangers involved with this gas. In the meantime a semiconductor sensor has been developed which can measure hydrogen concentrations down to 0,5ppm. The hydrogen content in the atmosphere is also only 0,5ppm (ten times lower than the background of helium). Therefore it becomes interesting to search for leaks with a test gas mixture of 5% hydrogen and 95% nitrogen. This gas mixture is neither inflammable nor explosive.

Helium (1)

Helium is a tracer gas used to find leaks for a multitude of reasons. Some advantages of Helium are:

- Non-toxic
- Inert and non-condensable
- Normally not present in the atmosphere at more than trace amounts
- Relatively inexpensive
- Readily passes through leaks due to its small atomic size
- Non-flammable

Disadvantage is that Helium is sometimes difficult to get. The only molecule smaller than Helium (mass 4) is Hydrogen (mass 2), which is not inert. Helium is much lighter than the next heavier inert molecule, Neon (mass 20) which is much more expensive. Helium is present at a concentration of only 5ppm in normal atmospheric conditions.

Helium (2)

To reach a better sensitivity that the method ‘Helium (1)’ a vacuum method is developed. The air of the inner part of the object under test pumped out so that a vacuum is created. The outer part of the object under test is exposed to helium and at the vacuum pump the presence of helium is detected.

Pressure decay

Pressure decay is commonly used in plumbing and many other industries. It may only involve a compressor and a pressure gauge, though some systems can be much more complex and expensive. The sensitivity of this method is proportional to time but generally limited to 10^{-4} atm cc/second. Another problem with this method is that fluctuations in temperature degrade the accuracy of the tests.

Bubble Testing

Bubble Testing is a common method of leak detection in industry today. It can be as simple as pressurizing a part, placing it under water, and looking for leaks. It can also be done by pressurizing the part with air, applying a soapy solution, and looking for bubbles. This method is simple and cost effective for locating large leaks but also has its drawbacks. The test piece gets wet and may therefore need drying. The method is not very sensitive.

Microflown method

The Microflown leak detection solution is based on the direct measurement of the particle velocity induced flow of the leakage. It is qualified to be able to detect a leak of $7 \cdot 10^{-6}$ bar l/s. This is much smaller than the other leak detection solutions except the helium leak detector, but helium detector needs vacuum in order to measure this leaks.

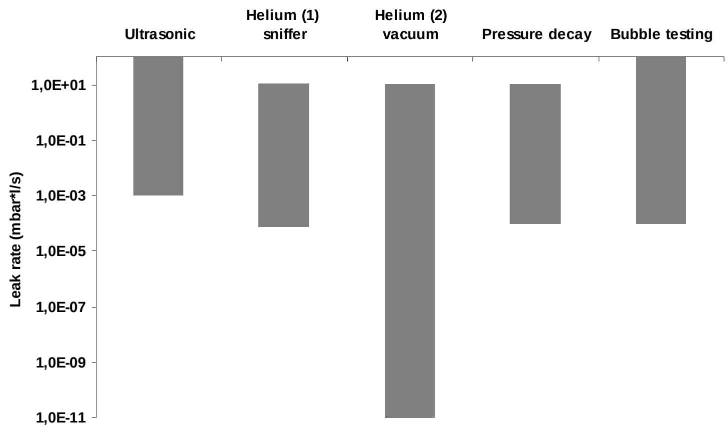

Fig. 18.3. Leak rate comparison of different methods.

18.4 Microflown Method

The Microflown sensor measures particle velocity directly and this is closely related to flow. Extensive testing shows that this method is able to detect very small leaks. Of course the ability of detection of a leak depends on the leak size and the testing pressure. The leak detection solution with the Microflown probe can be applied in two different set-ups. The first solution is with a moving probe, the second with a moving surface.

Moving probe

The leak can be located by moving the probe along the surface to be tested. As soon as the leak is detected the equipment gives a signal. The method most suited to be performed by hand. In order to retrieve the best results, good alignment before the leak is essential for detecting the leak. As soon as the leak appears, next to the signal of the equipment a sound can be heard.

Under here 3 samples of detected leaks at 4 bar:

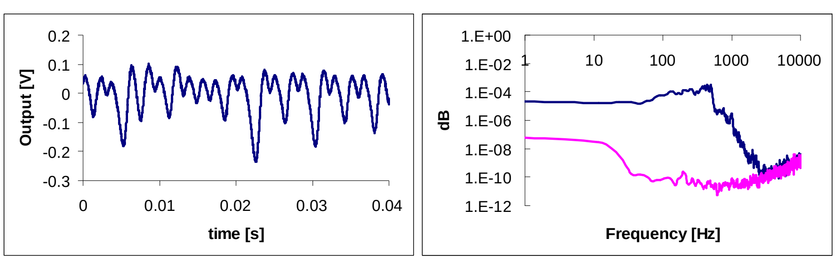

Fig. 18.4: Leak at 4 bar, leak size 3 micron. Left time signal, right representation in the frequency domain (Blue: leak signal, pink: no-leak signal).

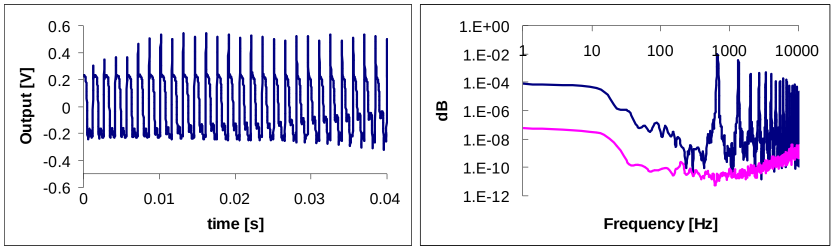

Fig. 18.5: Leak at 4 bar, leak size 5 micron. Left time signal, right representation in the frequency domain (Blue: leak signal, pink: no-leak signal).

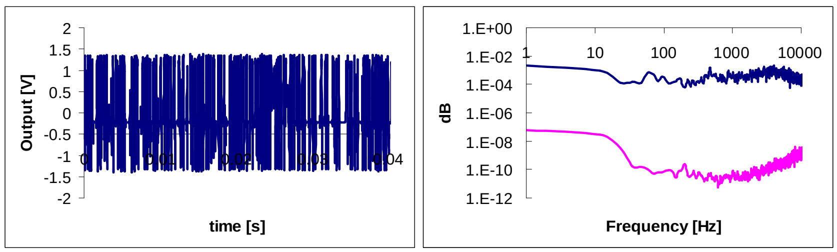

Fig. 18.6: Leak at 4 bar, leak size 10 micron. Left time signal, right representation in the frequency domain (Blue: leak signal, pink: no-leak signal).

Moving surface

This leak detection method is developed for fast, automatically and accurate leak detection. This method is ideal for objects with a testing surface which can be rotated. The signal of the leak detection equipment can be connected to a computer for further processing. Under here 3 samples of detected leaks:

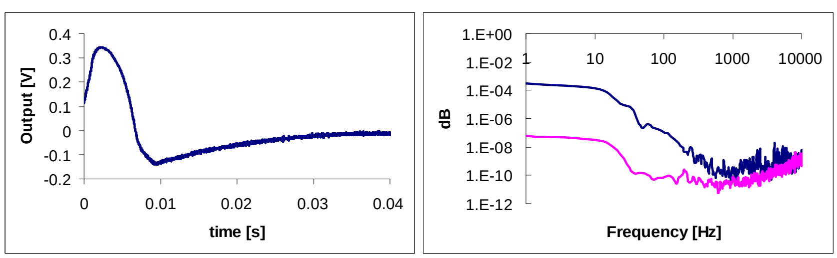

Fig. 18.7: Leak at 4 bar, leak size 3 micron. Left time signal, right representation in the frequency domain (Blue: leak signal, pink: no-leak signal).

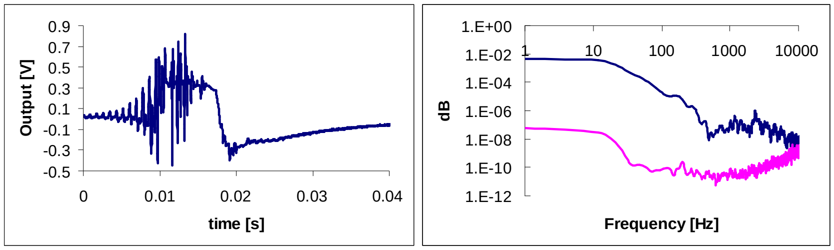

Fig. 18.8: Leak at 4 bar, leak size 5 micron. Left time signal, right representation in the frequency domain (Blue: leak signal, pink: no-leak signal).

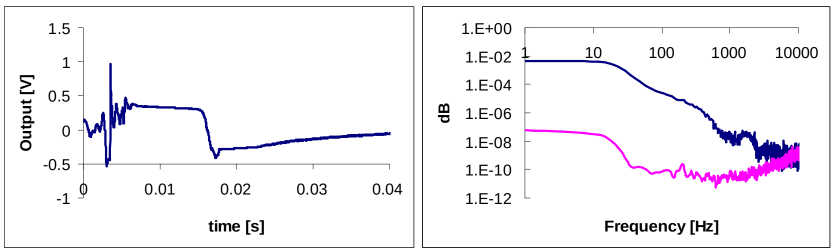

Fig. 18.9: Leak at 4 bar, leak size 10 micron. Left time signal, right representation in the frequency domain (Blue: leak signal, pink: no-leak signal).

Determination of the sensitivity

The sensor measures the velocity of air particles in m/s. This has to be related to the smallest leak that can be detected in mbar*l/s. For this purpose several methods are used. In the following paragraphs the size of the leaks are determined so that it matches the standard for rims.

First the theoretical leak rate and flow rate are calculated with software found on the Internet, the results are found in Table 1. Then this theoretical value is compared with a pressure decay measurement and a helium leak tester. Finally a small orifice is also measured in water to test if this leads to usable results.

Gas flow through small calibrated orifices

With a fixed temperature gas type and certain overpressure the leak rate can be determined [4]:

Leak rate: $$q = C \times \frac{\Delta p * d^2}{\sqrt{T}}, \left[std \frac{l}{s} \right] \qquad (3)$$

With *C* a certain constant, *Δp* the pressure drop, *d* the orifice diameter and *T* the temperature.

The standard leak rate, L, is the rate when the pressure differential is one bar. From the theory can be shown this standard leak rate is almost constant, Table 1.

From the orifice manufacturer [4], *Table 1*.

Overpressure [bar]	Leak rate [10-6 std l/s]					Standard leak rate [10-3 std l/s @ 1bar overpressure]				
	5µm	4µm	3µm	2µm	1µm	5µm	4µm	3µm	2µm	1µm
1	7,2	4,6	2,6	1,2	0,3	7,2	4,6	2,6	1,2	0,3
2	10,7	6,9	3,9	1,8	0,4	5,4	3,5	2,0	0,9	0,2
3	14,3	9,2	5,4	2,3	0,6	4,8	3,1	1,8	0,8	0,2
4	17,8	11,4	6,5	2,9	0,7	4,5	2,9	1,6	0,7	0,2
5	21,4	13,7	7,7	3,5	0,9	4,3	2,7	1,5	0,7	0,2
6	25,0	16,0	9,0	4,0	1,0	4,2	2,7	1,5	0,7	0,2

Table 1: The standard leak rate of a small orifice is almost independent on the pressure

As can be seen, the leak rate is almost linear dependent on the overpressure. This means that if the overpressure doubles, the leak rates doubles too. The standard leak rate is almost independent on the overpressure. Only at a low overpressure the standard leak rate goes up.

From this theory the size of the leak must be between 1µm and 2µm to for the norm.

Pressure drop measurements to determine the leak rate

The leak rate of an orifice can be different from theoretical value and therefore has to be measured. A setup is build that consists of a 1 litre pressurized vessel on which different orifices can be mounted. To determine the exact leak rate a pressure decay measurement is done in a temperature controlled room with five different orifices purchased from Lenox Laser in the USA (orifice diameters 1µm, 2µm, 3µm, 4µm and 5µm), Fig. 18.10.

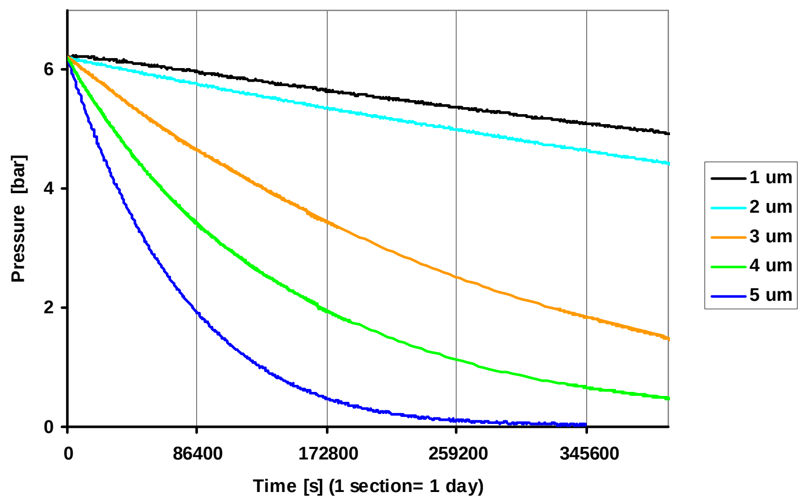

Fig. 18.10: Pressure decay measurements on five different orifices.

The leak rate of an orifice can be calculated from the pressure readout. The ratio of the leak rate and the overpressure gives the standard leak rate value at 1bar.

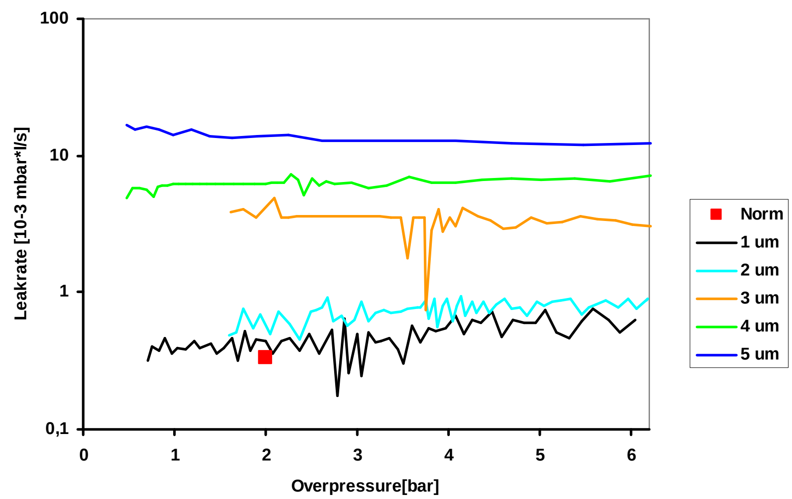

Fig. 18.11: Standard leak rate (at 1bar) calculated from pressure drop measurements.

As can be seen, the leak rate of a 1µm and a 2µm orifice almost overlap. Therefore can be concluded from the pressure drop measurements that the leak must be close to a 1µm or 2µm large leak to meet the standard.

Helium leak tester measurements

A helium leak tester is capable to measure a leak and also the leak rate. Orifices of several sizes are measured with four different helium leak testers. Helium leak tester 1-3 had consistent results and helium leak tester number 4 was completely different so this tester was not used anymore.

From the measurements it shows that the norm ($3x10^{-04}$ mbarl/s) is found for a leak size between 1µm and 2µm.

Orifice [µm]	Tester 1 mbar l /s	Tester 2 mbar l /s	Tester 3 mbar l /s	average	Tester 4 mbar l /s
5	4,91E+00	1,08E+01	8,09E+00	6,27E+00	$5*10^{-05}$
5		8,38E+00	5,44E+00		
5			5,29E+00		
4	2,72E-03	3,81E-03	2,45E-03	2,77E-03	
4			2,94E-03		
4			2,92E-03		
3			1,43E-03	1,47E-03	
3			1,60E-03		
3			1,38E-03		
2			7,73E-04	9,15E-04	
2			7,11E-04		
2			1,26E-03		
1			2,59E-04	2,91E-04	
1			2,84E-04		
1			3,30E-04		

Bubble testing

A setup with a 1µm orifice was tested in a water setup at 3bar overpressure. It shows that it is possible to detect such leak. One tiny bubble per 15 seconds was noticed. With this set up it is impossible to determine the leak size but it is possible to find the location of the leak and to demonstrate if one leak is larger than another. The method is not very suitable to industrialize.

Leak detection measurements

Different orifices are mounted in a pressurized rim. The particle velocity sensor is scanned over the hole. It is possible to detect a 3µm orifice with sufficient signal. With some effort it is possible to detect a 2µm orifice. The overpressure must be 7bar for this.

The overpressure is varied and the minimal measurement distance from the orifices is determined, Error! Reference source not found..

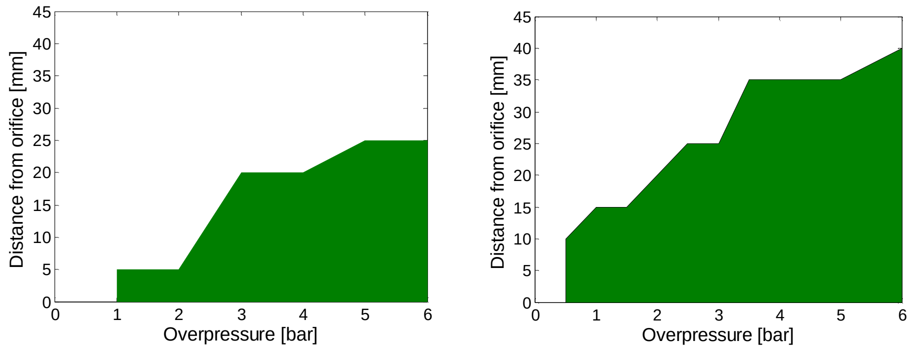

Fig. 18.12: Minimal measurement distance of a 3μm hole (left) and a 5μm hole (right).

Also a 10μm orifice, a 20μm orifice and different larger holes of which the exact diameter is unknown are measured. These leaks can be detected without problems at larger distances.

Even with a low overpressure it proved to be easy to detect the leakage of a 3 microns orifice. At 1 bar overpressure the leak is detectable at 5mm. A 2 micron orifice can be measured if the overpressure is 7 bar. It can be concluded that it is possible to reach the norm with this method.

If an orifice of 1micron can be detected, the method would be more sensitive than the norm would require. It is recommendable that the sensitivity of the method is increased so that a 1 micron orifice can be detected. In that case the method has proven itself to be more sensitive than the norm.

18.5 Microflown leak detection examples

Below some examples of leak detection applications are shown.

Leak detection of packages

Quality control of packages is done with random checks. During this check the leak tightness of the package is tested. Once it is determined that the package is leak (this is often not very difficult to find out), with the Microflown leak detection method the exact place of the leak is found. With that knowledge packaging machines are adjusted optimizing the production process. This Microflown leak detection method is an out-of-line check performed by hand.

Fig. 18.13: Leak testing of a package.

Leak detection of welds

For applications using compressed air, leak tight welds are important. The leak tightness quality is checked with the Microflown. The leak tightness can be examined by pressurizing the application and check the welds with the Microflown. For lower quantities the check is performed by hand and for high quantities the process is automated. The check is naturally done at the end of the welding process.

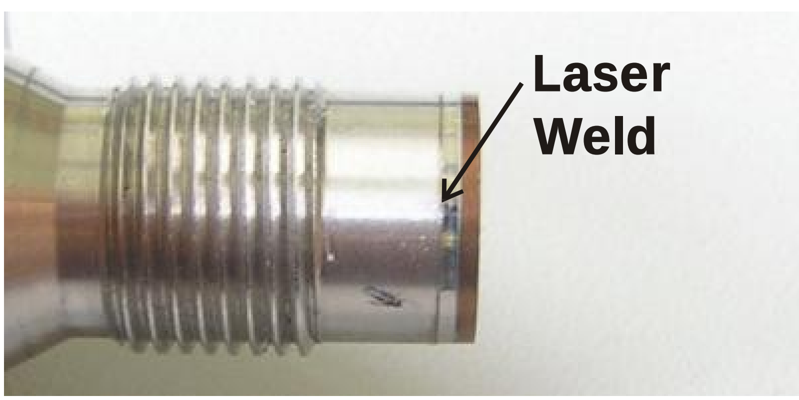

Fig. 18.14: Leak testing of a laser weld.

The weld testing can also be applied on testing tins.

Leak detection of filters

This particular filter is build up out of several small tubes. These filters have an end of line check for the right flow capacity of each tube. When the flow of a tube exceeds a certain value the tube has a leak. The Microflown probe is capable of qualifying the leak and track the position. Other leak detection methods tend to fail because each pore of the filter 'leaks' and only the higher leak rate has to be found.

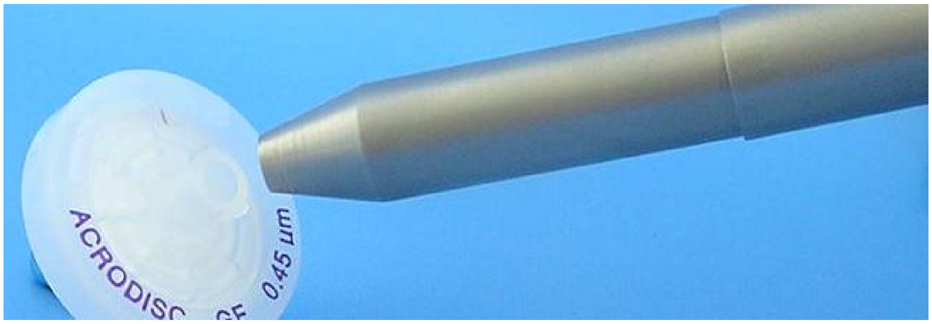

Fig. 18.15: Leak testing of a filter.

Leak detection of bottles

In this specific application drink bottles are used at intensive care departments of hospitals. These bottles have to be complete leak tight in order to prevent bacillus to come in. The check is performed end of line.

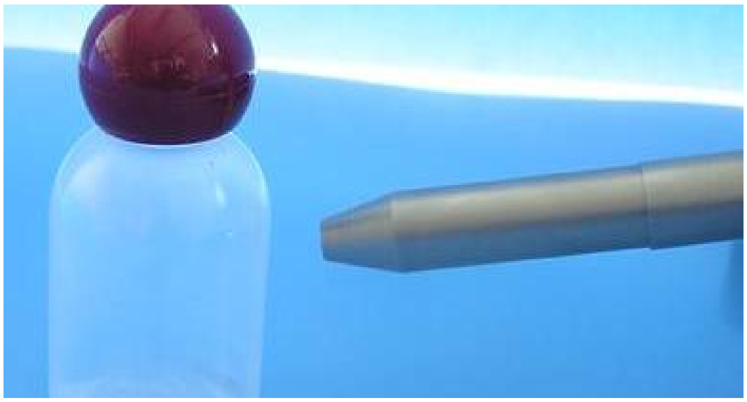

Fig. 18.16: Leak detection of a bottle.

Leak detection of rims

The first leak tester prototype for rims is shown in Fig. 18.1. It is able to operate on the air pressure system available in most production facilities.

The cycle time including on- and off-loading is one minute of which 40 seconds measuring time.

The rim is pressurized from the inside and the outside of the rim is scanned with 4 sensor pairs. The rim is rotated and the sensor head is moved at a constant distance from the surface along the rim profile. Two sensor pairs are positioned under an angle to measure oblique parts of the rim profile. The two middle sensor pairs are positioned straight to increase the measurement speed on the vertical parts of the surface to reduce cycle time.

A run of several thousands of rims was tested with the new leak tester and with a helium leak tester. The rims that where tested as being leak with the helium leak tester where measured again with the helium leak tester because this type of tester has many 'false leak detections' due to leaks in the sealing etc.

The rims that the helium leak tester marked as leak where also tested at the new leak tester.

All rimes that found leak on the helium leak tester where also detected leak on the new leak tester. Except for one rim. This rim was also tested with the water bubble technique and no leak was found. Because the water bubble technique was also to detected the leak the conclusion was that the helium leak tester gave a 'false leak detection'. However no reason for this false leak detection was found.

The engineers that operated the helium leak tester always retested a rim identified as 'leak' to distinguish a real leak from a incorrect sealing. Only if there still was doubt the water bubble technique is used. If the new leak tester is compared with the helium leak tester and the water bubble leak testing method we can conclude that the helium leak tester can show false leaks and that the bubble leak tester is very consistent but very unpleasant to use.

The test showed that the new leak tester is very reliable: rims that are tested as leak are found to be leak on both the helium leak tester and the water bubble technique. The new leak tester can be more convenient than the helium leak tester. This is because the method does not use a rare consumable (i.e. Helium that is sometimes not available), the method uses simple air that can be found 'in the wall'. Rims can be tested in different stages of the production process even when the rim is relative dirty.

Leaks that where found in the helium leak tester are also found in the new leak tester with one exception. This one leak was also not found in the water bubble technique indicating that the helium leak tester gave a 'false leak'.

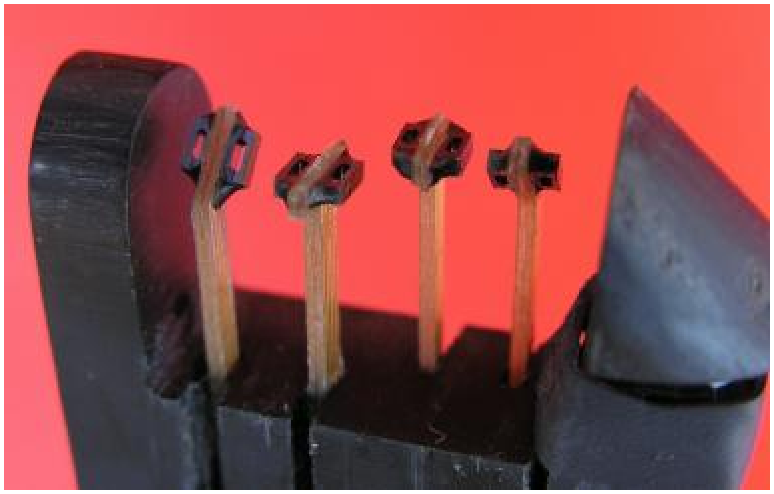

Fig. 18.17: probe head for leak detection of rims.

A new leak test method for rims has been developed based on a unique particle velocity sensor. Laboratory test on a pressurized vessel with small orifices show it is possible to measure a 3μm orifice at 1 bar overpressure. Even leaks with a size of 2 micron can be detected at a higher pressure. This indicates that the new leak tester reaches the norm for rims.

As a result of these promising laboratory tests a leak tester for rims is build by Fontijne Grotnes. The advantages are:

- Uses normal air (no rare consumable)
- Operates at relative low overpressure (6 bar or lower)
- No false leaks (as can be experienced with helium leak tester)
- Rims may be dirty (not possible with helium leak tester)
- Similar cycle time as helium leak tester
- Pin points leak (just as water bubble technique)
- Similar sensitivity as helium leak tester and water bubble technique

18.6 References

[1] Emiel Tijs et al., New fast leak detection method based on a particle velocity sensor, 2007

[2] optoelectronics.perkinelmer.com/ content/RelatedLinks/Articles/ATL_AerospaceLeakTest.pdf

[3] http://www.varianinc.com.cn/products/vacuum/ leakdetect/shared/leakdetect-catalog.pdf

[4] www.lenoxlaser.com/calculator/orifice.asp